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From:
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Date:
December 19, 2012

ARCADIS Project No.:
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Subject:
King Highway Landfill OU – Flow Reversal Determination Prior to Groundwater Sampling Events

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This technical memorandum provides a process for assessing groundwater flow reversal conditions at the King Highway Landfill (KHL) using real-time flow data from the United States Geological Survey's (USGS) Comstock River Gage Station[1] (Comstock gage), which is located approximately 2 miles upstream of the KHL. Refer to Figure 1 for the location of the KHL and the Comstock gage. The Michigan Department of Environmental Quality (MDEQ) requires that 2 weeks of elevation data be collected prior to groundwater sampling at the site to assess potential groundwater flow reversal conditions. The process in this technical memorandum was developed to help determine whether using instantaneous flow data available via Internet from the USGS gage at Comstock could replace the physical collection of river and groundwater elevation data by a sampling crew. To develop this process, existing groundwater and Kalamazoo River elevation data were used to assess whether the occurrence of groundwater flow reversal conditions at the KHL can be predicted remotely from flow data from the Comstock gage. This technical memorandum presents four sections: Groundwater Flow and Data Evaluation, Seasonal Flow Analysis, Process, and Recommendation.

Groundwater Flow and Data Evaluation

Groundwater beneath the KHL is derived from infiltration of precipitation falling on uncapped portions of the site and from groundwater entering the site from areas of higher hydraulic head. The majority (approximately 75%) of the KHL was capped as a component of the remedial action implemented in accordance with the February 2000 Administrative Order by Consent signed by MDEQ. Capping reduces the amount of recharge to the groundwater table over the area covered

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[1] http://waterdata.usgs.gov/usa/nwis/uv?04106000

by the cap, and increases the volume of water directly entering the river via surface runoff. Therefore, a majority of the groundwater flowing beneath the KHL enters the river from upland areas generally to the west and southwest. The water table beneath the KHL is principally in the upper-sand unit, but also likely occurs in the paper-making residuals in portions of the former landfill cells. As a result, shallow groundwater flows toward, and discharges to, the Kalamazoo River. However, based on elevation data collected from the river (KHL river staff gage RG-6) and groundwater (monitoring well MW-3AR) during past 8 years of groundwater monitoring events, there are times when the river water elevation can be slightly higher than the groundwater elevation, which is in theory a negative gradient. The MDEQ has expressed concern that this could be indicative of reversed flow (i.e., flow from the river to the groundwater) and could potentially dilute the concentration of PCBs in groundwater, which would affect groundwater monitoring results.

To assess whether groundwater flow reversal conditions at the KHL can be predicted remotely from the Comstock gage, the following data collected from November 18, 2002 through August 27, 2010 were used:

- Groundwater elevation data from existing monitoring well MW-3AR
- Kalamazoo River elevation data from the river staff gage RG-6
- Flow data from Comstock gage

Existing data from monitoring well MW-3AR and river staff gage RG-6 were used due to their proximity to each other (Figure 2).

To evaluate the relationship between flow measured at the Comstock gage and the gradient between monitoring well MW-3AR and river staff gage RG-6, the 15-minute average flow data at Comstock gage were plotted against corresponding elevation data from RG-6 and MW-3AR. The results show that the instantaneous flows at the Comstock gage are significantly correlated ($p<0.01$ and $\alpha=0.05$) to water elevation in RG-6 (Chart 1) and groundwater elevation in MW-3AR (Chart 2). "Significantly correlated" means that there is less than 1 percent chance that the Comstock gage flows and water elevations at RG-6 and MW-3AR are randomly related. These plots indicate that the groundwater elevations and river flow tend to rise and fall together in a very predictable way, as indicated by the R^2 values (0.84 and 0.94 for RG-6 and MW-3AR, respectively). Based on the R^2 values, the Comstock gage flow data would be a good predictor of river elevation at RG-6 and groundwater elevation at MW-3AR.

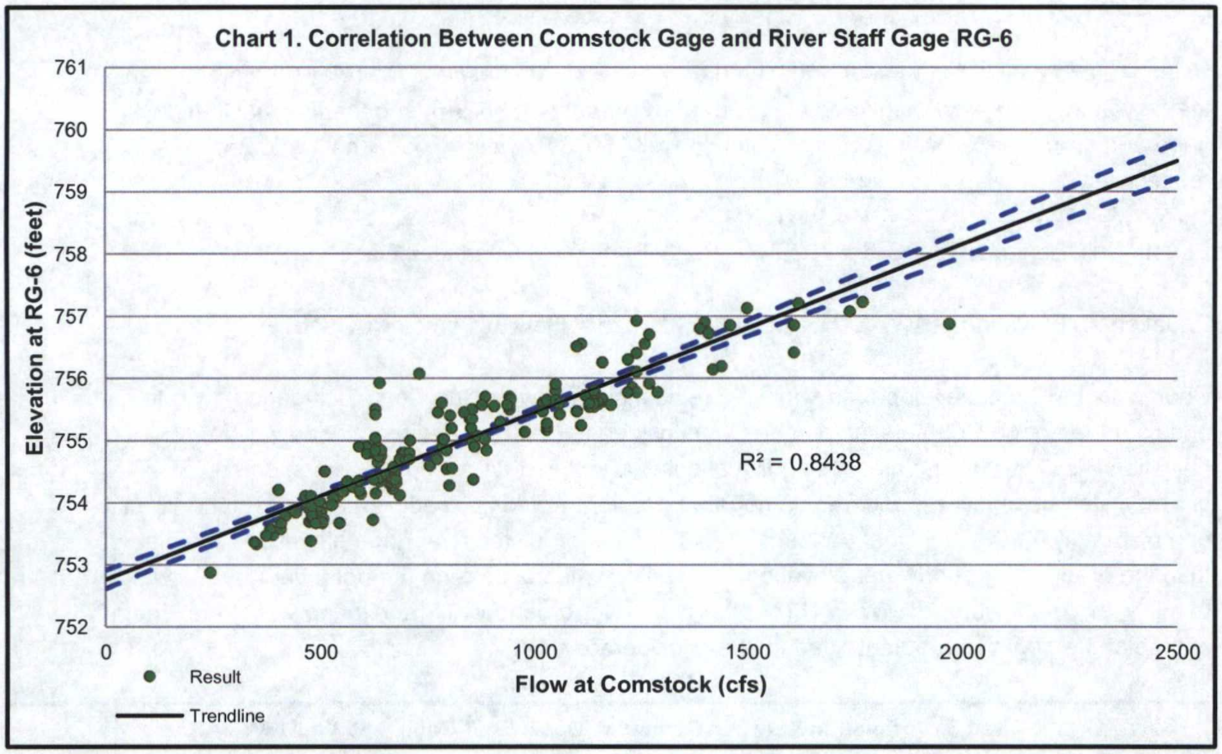


Chart 1. Correlation Between Comstock Gage and River Staff Gage RG-6
Elevation at RG-6 (feet)
761
760
759
758
757
756
755
754
753
752
0
500
1000
1500
2000
2500
Flow at Comstock (cfs)
R² = 0.8438
Result
Trendline

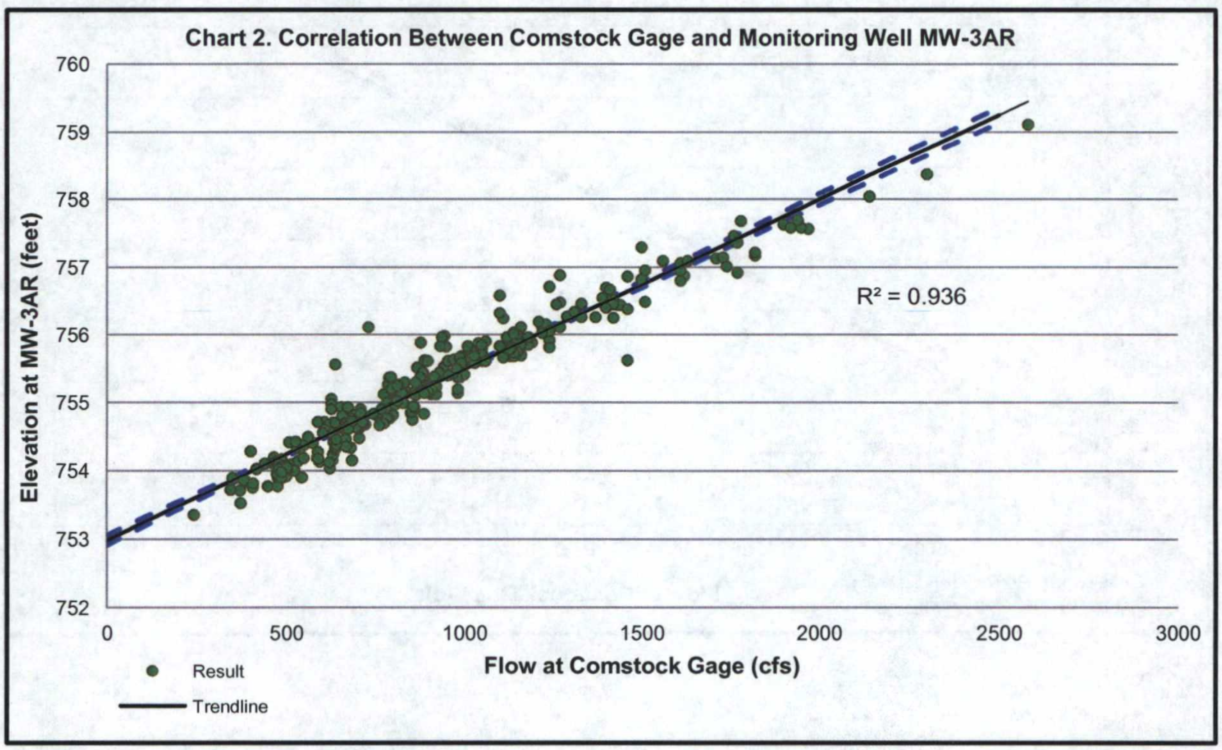


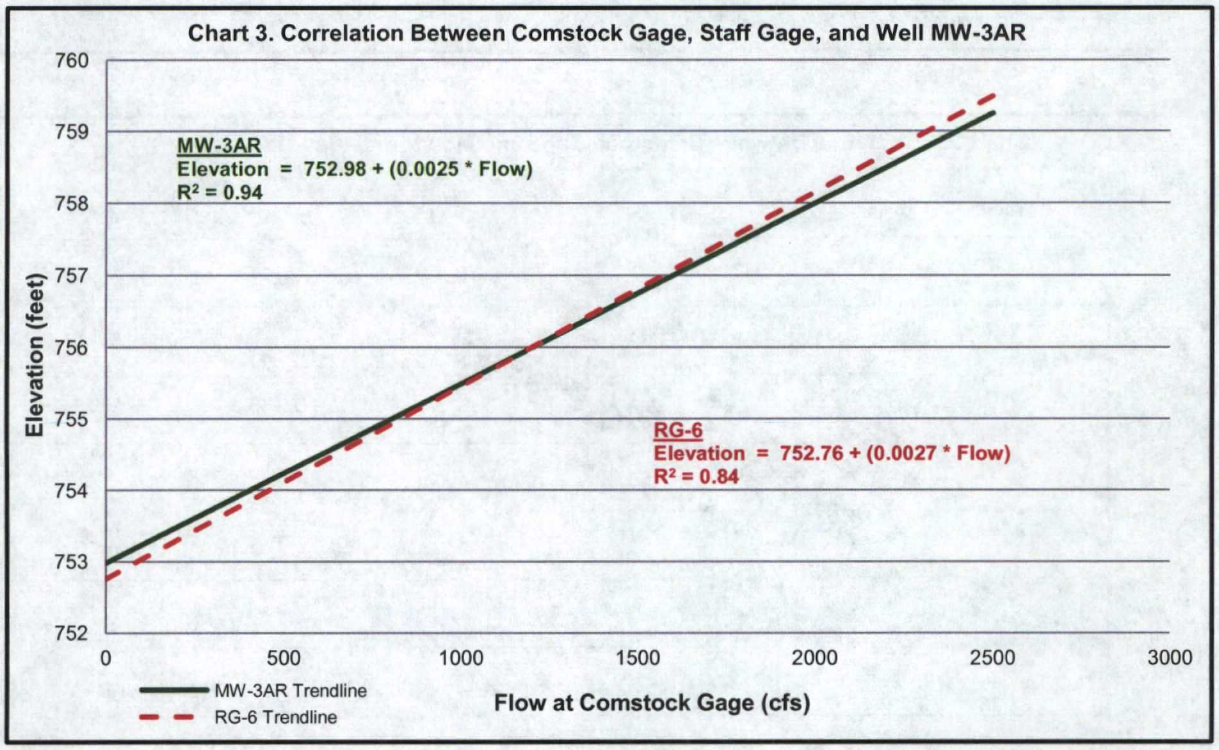
Chart 2. Correlation Between Comstock Gage and Monitoring Well MW-3AR
Elevation at MW-3AR (feet)
760
759
758
757
756
755
754
753
752
0
500
1000
1500
2000
2500
3000
Flow at Comstock Gage (cfs)
R² = 0.936
Result
Trendline

Using the expression for a linear equation (i.e., y = b + mx) to describe the relationship between the flow at the Comstock gage and elevation at river staff gage RG-6, and the flow at Comstock gage and groundwater elevation at monitoring well MW-3AR yields Eqautions 1 and 2, respectively.

Equation 1: Elevation at RG-6 = 752.76 + (0.0027 × Flow at Comstock Gage)

Equation 2: Elevation at MW-3AR = 752.98 + (0.0025 × Flow at Comstock Gage)

Chart 3 (below) was developed to show the relationship between the Comstock gage flow rate and river staff gage RG-6 elevation, and Comstock gage flow rate and monitoring well MW-3AR elevation. As Chart 3 illustrates, using Equations 1 and 2 to determine river elevation and groundwater elevation, respectively, a negative gradient would be predicted at flows higher than approximately 1,100 cubic feet per second (cfs), as the predicted river gage elevations are higher than the predicted groundwater elevations. However, when assessing the potential for river water to mix with groundwater at MW-3AR (or other perimeter groundwater monitoring wells) the length of time of the negative gradient needs to be considered.



In order to have surface water flow from the river to a monitoring well, the gradient would need to be sustained for a period of time that is influenced by the distance from the surface water to the well, the hydraulic gradient, and the properties of the soil. The following equation was used to estimate the amount of time required for surface water to flow from the river to the wells:

$$\bar{v} = \frac{(K \times I)}{n_e}$$

$\bar{v}$ = average linear velocity;
K = hydraulic conductivity;
I = hydraulic gradient; and
n_e = effective porosity.

The hydraulic conductivity measurements for the native river deposits, as reported in Technical Memorandum 6 for the KHL (BBL, 1994), range from $1.0E^{-2}$ to $2.5E^{-2}$ centimeter per second. Because hydraulic conductivity values for the paper-making residuals are several orders of magnitude lower, using the values for the native river deposits results in a conservative time estimate.

The graphic presentation of the elevations at monitoring well MW-3AR and river staff gage RG-6, Chart 3 (above), illustrates that when there is a higher hydraulic head in the river compared to groundwater, the elevation difference is slight, generally less than 0.5 foot, and typically much lower. Again, in order to provide a conservative estimate, a hydraulic gradient of 0.01 was used, based on an elevation change of 0.5 foot over a distance of 36 feet between monitoring well MW-3AR and river staff RG-6. Using an estimated effective porosity value of 0.2, the average linear velocity is approximately 1.4 to 3.5 feet/day. Using these values, the gradient difference of 0.5 foot between the river and the wells would need to be maintained for approximately 10 to 25 days to allow river water to reach monitoring well MW-3AR at a distance of 36 feet from the river.

Table 1 below provides the distances from each of the KHL monitoring wells to the Kalamazoo River. Based on the distances provided below, monitoring well MW-3AR is representative of the other down-gradient monitoring wells on-site that are most likely to be affected by flow reversal conditions.

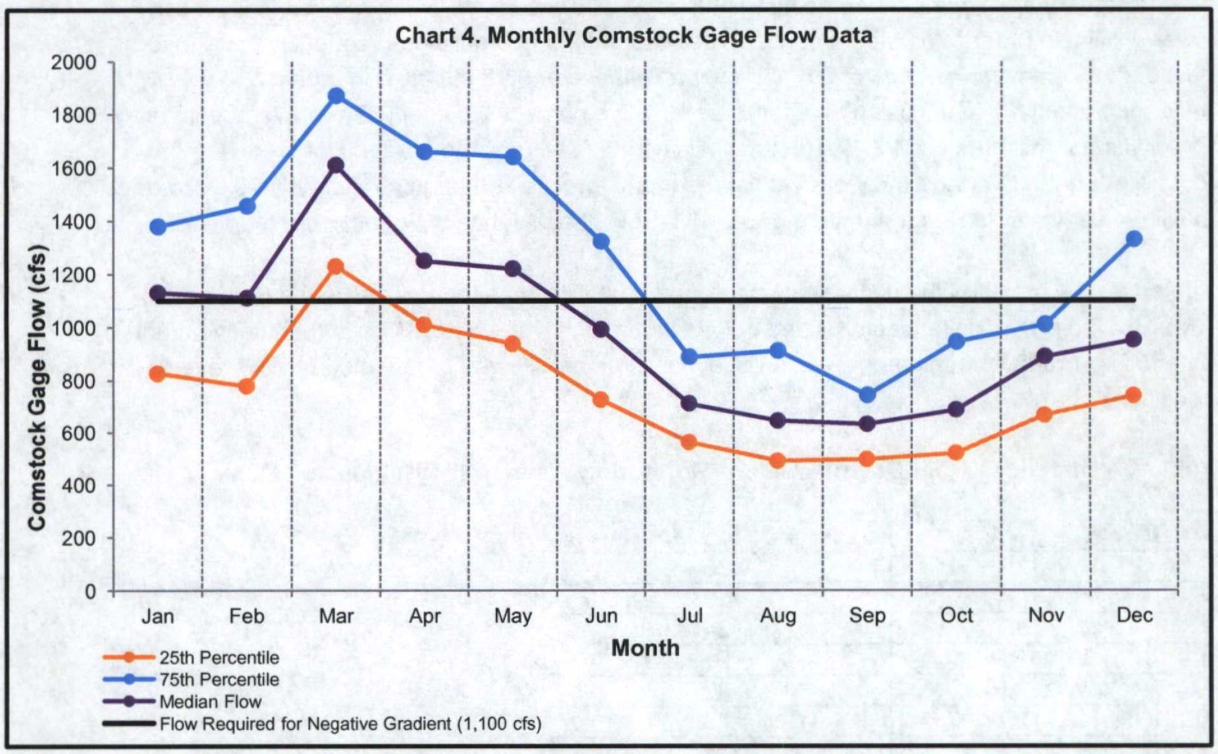
Table 1 – Distances from Down-Gradient Monitoring Wells to the Kalamazoo River

Monitoring Well ID	Distance to River (feet)
MW-3AR	36
MW-8AR	19
MW-8BR	24
MW-11RR	61
MW-12AR	27
MW-12B	26
MW-13AR	21

Monitoring Well ID	Distance to River (feet)
MW-13B	24
MW-14AR	40
MW-15AR	29
MW-16A	19
MW-16B	18

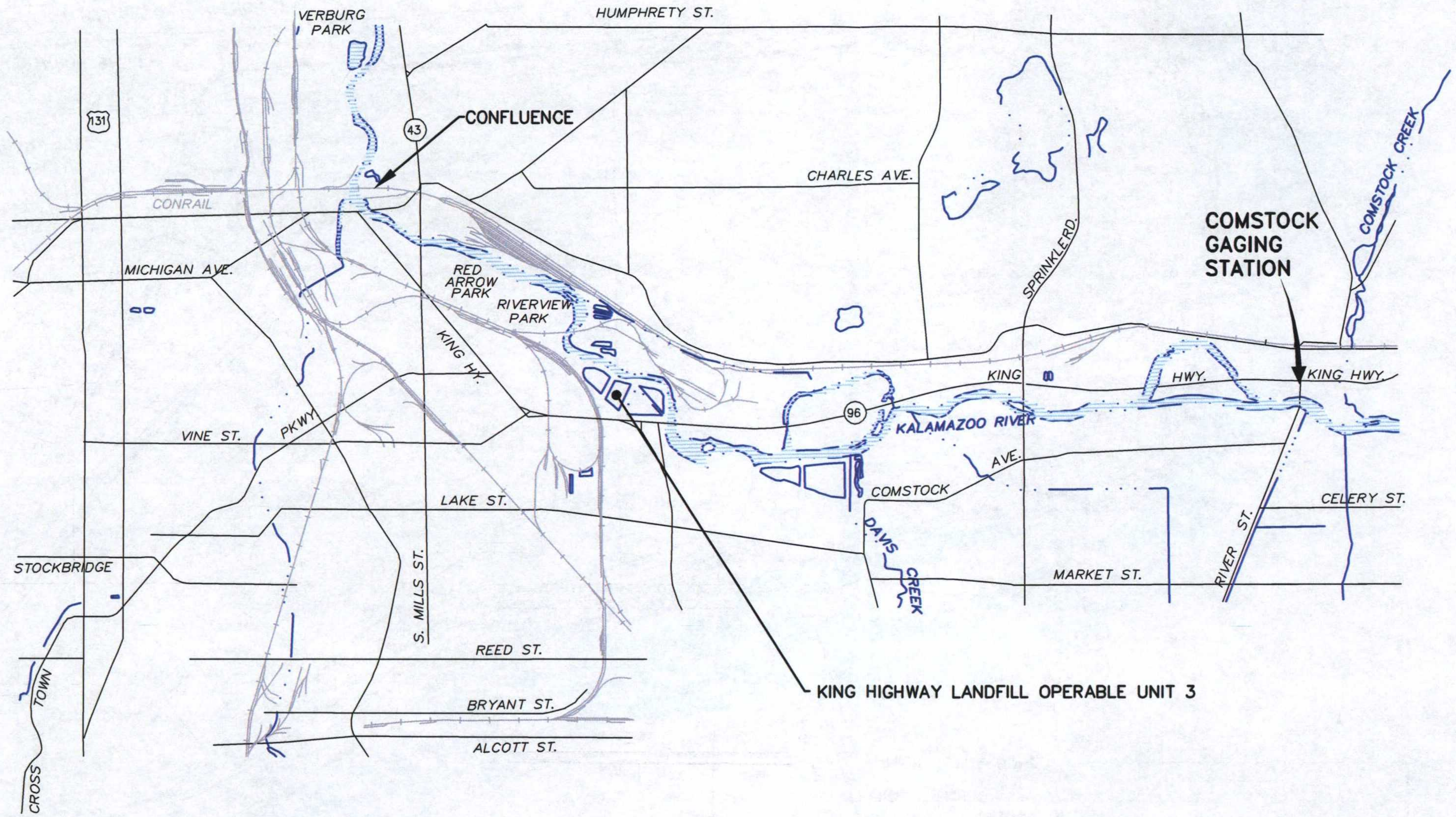
Seasonal Flow Analysis

The 2002 to 2012 flow rate measured at the Comstock gage was analyzed to determine the seasonal variation of the flow rate within the Kalamazoo River (Chart 4). Based on this analysis, the median flow rate of the Kalamazoo River for the months of January through May, as measured at the Comstock gage, was greater than the flow rate required for a negative gradient at the KHL (i.e., 1,100 cfs). Conversely, during the months of June through December, the median flow rate at the Comstock River gage was less than 1,100 cfs, with the lowest median flow rate measured during the months of August and September. Furthermore, the 75th percentile flow measured at the Comstock gage for the months of July through November were less than the flow required for a negative gradient at the KHL. These data indicate the best timeframe for conducting the annual groundwater sampling event would be during the months of August and September, when the potential for a negative gradient at the KHL is the lowest.



Process

Based on the information and evaluation above, the following process is proposed for assessing groundwater flow conditions at the KHL prior to groundwater sampling. One week prior to a scheduled sampling event, the Comstock gage would be monitored via the Internet, and the flow would be recorded for the previous 14 days. If the flow at Comstock gage remains below 1,100 cfs for the one-week period or if the recorded flow exceeds 1,100 cfs, but is maintained for less than 1 day (i.e., $^{1}/_{7}$ of the estimated 7 days), the sampling would proceed as scheduled. If during the one-week monitoring period flows in excess of 1,100 cfs are consistently recorded for more than 1 day, Georgia-Pacific (or ARCADIS) will contact MDEQ to discuss the need to reschedule the sampling event. Sampling will be scheduled for the summer months (i.e., August and September) when extended periods of flows less than 1,100 cfs are more common, based on the analysis provided below.



NOTES:

1. PLANIMETRIC MAPPING OBTAINED FROM MICHIGAN RESOURCE INFORMATION SYSTEMS.

0 2400' 4800'

GRAPHIC SCALE

ALLIED PAPER, INC./PORTAGE CREEK/
KALAMAZOO RIVER SUPERFUND SITE
FLOW REVERSAL DETERMINATION PRIOR TO ANNUAL GROUNDWATER SAMPLING EVENTS

SITE LOCATION MAP

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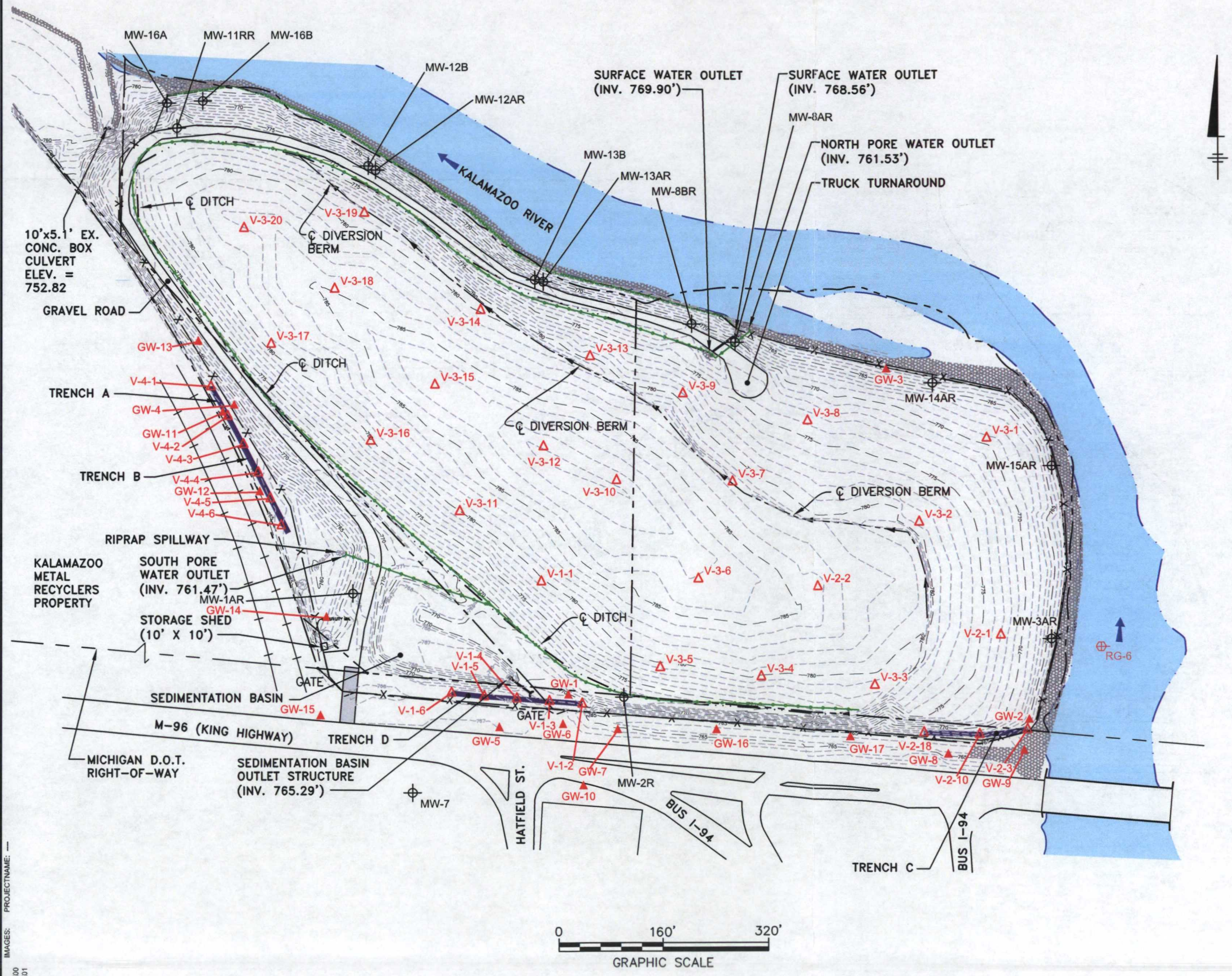
FIGURE
1



LEGEND:

- APPROXIMATE PARCEL BOUNDARY
- DITCH LINE
- ABANDONED RAILROAD
- SHEETPILE WALL
- ACCESS ROAD
- RIPRAP
- CULVERT PIPE
- FINAL AS-BUILT INDEX CONTOUR
- FINAL AS-BUILT INTERMEDIATE CONTOUR
- SECURITY FENCE
- PORE WATER COLLECTION PIPE
- PORE WATER DRAIN
- APPROXIMATE WATER EDGE
- V-1-2 GAS VENTS
- LANDFILL GAS CUTOFF TRENCH
- FLOW DIRECTION
- MW-14 MONITORING WELL
- RG-3 FORMER RIVER GAUGE STATION (NO LONGER IN USE)
- GW-2 LOCATION OF GAS MONITORING PROBES

NOTES:

1. BASE MAP INFORMATION OBTAINED FROM CADD DRAWING FILE DEVELOPED BY RMT, INC., ANN ARBOR, MICHIGAN (CADD FILE: L1630SU01.DWG AS-BUILT SURVEY; 8/21/00).
2. FINAL AS-BUILT CONTOUR ELEVATIONS ARE SHOWN AND ARE BASED ON A FIELD SURVEY BY ATWELL-HICKS, INC., DATED 9/27/00 WITH REVISIONS DATED 10/23/00, 12/21/01, 12/10/02, AND 7/24/03.
3. ELEVATIONS ARE BASED ON NGVD OF 1929 (MSL).
4. PROPERTY SURVEY PERFORMED BY WILKINS & WHEATON ENGINEERING CO., INC., ON 7/1/96.
5. TOPOGRAPHIC CONTOUR INTERVAL IS 1 FOOT.
6. LOCATIONS OF GW-5, GW-6, GW-7, GW-8, GW-9, AND GW-10 ARE BASED ON A FIELD SURVEY BY TERRA CONTRACTING LLC, DATED 9/23/05.
7. LOCATION OF GW-11 IS BASED ON A FIELD SURVEY BY TERRA CONTRACTING LLC, DATED 1/11/06.
8. LOCATIONS OF RG-6, V-4-4, V-4-5, AND V-4-6 ARE BASED ON A FIELD SURVEY BY TERRA CONTRACTING LLC, DATED 6/7/06.
9. LOCATIONS OF V-1-2 THROUGH V-1-6, V-2-3, V-2-10, AND V-2-18 ARE BASED ON MULTIPLE FIELD SURVEYS CONDUCTED BY TERRA CONTRACTING, LLC. IN APRIL 2008. GAS VENTS V-2-4 THROUGH V-2-9, AND V-2-11 THROUGH V-2-17 ARE NOT SHOWN FOR CLARITY PURPOSES (THESE VENTS ARE LOCATED ALONG TRENCH C).
10. LOCATION OF GW-12 IS APPROXIMATE.
11. LOCATIONS OF GW-13 THROUGH GW-17 BASED ON FIELD SURVEY CONDUCTED BY PREIN & NEWHOF ON 11/1/11.

ALLIED PAPER, INC./PORTAGE CREEK/
KALAMAZOO RIVER SUPERFUND SITE

FLOW REVERSAL DETERMINATION PRIOR TO ANNUAL GROUNDWATER SAMPLING EVENTS

KHL SITE PLAN

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FIGURE

2